SARDAR VALLABHBHAI PATEL LECTURES

The Unity and Diversity of Life

J. B. S. HALDANE

THIRD SERIES

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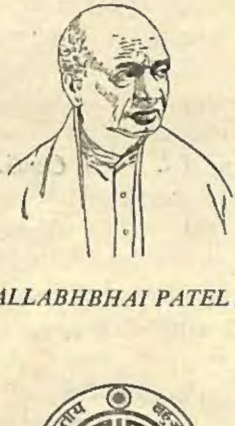
THE PUBLICATIONS DIVISION

THE UNITY AND DIVERSITY OF LIFE

J. B. S. HALDANE



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THE PATEL MEMORIAL LECTURES

All India Radio introduced in 1955 a programme of lectures in memory of Sardar Vallabhbhai Patel who, apart from the great role he played in the achievement and consolidation of freedom, was free India's first Minister for Information and Broadcasting. An annual feature, these lectures are intended to contribute to the existing knowledge on a given subject and to promote awareness of contemporary problems. Each year, some eminent specialist who has devoted thought and study to any branch of knowledge or public affairs is invited to give through All India Radio, in a popular manner, the results of his study and experience for the benefit of the public.

The first lecture on "The Good Administrator" was given by Shri C. Rajagopalachari in 1955. The second series was broadcast by Dr. K. S. Krishnan, F.R.S. in 1956. His theme was "The New Era of Science".

For the 1957 series All India Radio invited Professor J. B. S. Haldane, F. R. S., the distinguished biologist who has contributed to the sciences of biochemistry, physiology, genetics and mathematical statistics and has taught in the Universities of Oxford, Cambridge and London. He is now associated with the Indian Statistical Institute, Calcutta. His numerous writings include such well-known works as "Animal Biology", "Enzymes", "The Causes of Evolution", 'Heredity and Politics", "Science in Peace and War" and "The Biochemistry of Genetics".

Sardar Vallabhbhai Patel Memorial Lectures

DELIVERED AT VIGYAN BHAVAN, NEW DELHI, ON DECEMBER 15, 16 AND 17, 1957 AND LATER BROADCAST BY ALL INDIA RADIO.

I

THE GOVERNMENT OF INDIA has done me a very great honour in inviting me to deliver these lectures. I felt even further honoured when I learned that my predecessors had been Rajagopalachari and Krishnan. But worthy successors to them could certainly have been chosen from amongst my colleagues in this country. And I could, I believe, have given a better course of lectures after two or three years in India. By that time I hope not only to know your plants and animals better than I do, but to have learned enough Sanskrit to make a more direct contact with some of the great minds of India's past than is possible through translations and summaries.

Perhaps I should have done better to lecture on the subjects on which I am carrying out research and teaching at the Indian Statistical Institute, namely, genetics and statistics. If India had television I could perhaps have shown you different breeds of cows, hens, rice, jute, and so on, and told you something of how the differences between them are inherited, and what is their economic importance.

I have decided to deal with a more general topic both because I can speak of plants and animals which are very familiar to you, and because the question of unity and plurality has interested Indian thinkers for more than two thousand years. And I believe that this subject is particularly appropriate to a series of lectures commemorating Sardar Vallabhbhai Patel. His most remarkable single achievement was, I believe, the unification of the princely States into the Indian Republic, a task which India's enemies hoped, and her friends feared, would prove impossible.

What do I mean by the phrase "the Diversity of Life ?" I mean several different things. In the first place, there are many different sorts of living creatures, for example cows, koels, rice plants, and pipal trees. We use the word species to denote these different sorts, and there are more than a million of them. Secondly, each species consists of a great many members, and they are all a little different. Thirdly, each one of these is made up of different parts, such as hair and bone, leaves and roots, and can alter its behaviour, for example running at one time and eating at another, flowering at one time and fruiting at another.

You all know these facts. But perhaps you haven't thought about them very deeply, or in relation to India. For example, I might ask you: "How many species of flowering plants are there, and how many of these are native to India?" The answer gives you some idea of India's wealth.

Now, what do I mean by "the Unity of Life?" Roughly speaking, I mean that these diversities are much less real than they seem at first sight. First of all the theory of evolution, in which I believe, is that although a cow and a cobra, for example, look so different, they are descended from common ancestors. In this particular case we can go further, and say that the common ancestor lived at about the time when the British coal seams were being formed. Although the evidence is by no means so strong, there is evidence, some of which I shall put before you, that all living beings on our planet are descended from the same original ancestor. I need not tell you that Indian thinkers, in contrast to many but not all Europeans, have insisted on the kinship between men and animals, and on the presence of mind at least in some animals.

A plant or animal possesses a certain unity. Is this imposed on it by a soul which

is more or less independent of it, or is it an expression of the behaviour of its constituents like the unity of a family or of a nation? Indian thinkers have asked the parallel question about the human mind, and have given very different answers. Some Buddhist philosophers argued that the mind consisted of nothing but transient constituents; the *Vaiśeṣika* school argued that it had an atomic unity, and so on. Closely related with this is the problem of individuality. Both the Buddhist and *Advaita darśanas*, though in profound disagreement on other matters, have argued that *ahaṁkāra* is illusory. I shall take up this question on the biological rather than the mental level.

Thirdly, we may speak of unities such as the unity of a family of animals, including such very large families as an ants' nest. And here I shall have my one serious quarrel with traditional Indian thought. Your philosophers have used the phrase *mātsya nyāya*, fish logic, for the view that men have no duties to others, that the strong are justified in devouring the weak, as it is claimed that fish do. I shall try to defend fish against this calumny, and to show you that some fish at least set an excellent example to

human beings of fidelity to their husbands and wives, and care of their children, that others have a social life, and so on.

My first task, then, will be to say a little about the diversity of species and the evidence for their origin from common ancestors. We cannot give any sharp definition of a species. Roughly speaking, we mean a group of animals or plants differing in several characters from all other groups and without intermediates connecting them with another such group. In a few hundred cases we can say that two species are separate because we find that their members rarely mate, and if they do, give no hybrids, or sterile hybrids like mules and some cultivated bananas. But, of course, we only have such knowledge in very few cases.

Let us get a rough idea of the number of different species. The groups of animals most familiar to us are the mammals and the birds. The mammals, of course, are warm-blooded animals whose females suckle their young. Men, cows, dogs, rats, bats, whales, and so on are mammals. There are about 4,000 species of mammals and 8,000 of birds, and not many more are likely to be found. There are about 20,000 species of fish, and fewer of reptiles and amphibians such

as frogs, say 40,000 species of vertebrates altogether. On the other hand, there are nearly a million known species of insects and of these about 400,000 are beetles. Quite possibly another million insect species remain to be described, though I suspect the number is less. There are, perhaps, two lakhs of species of all other animals, molluscs such as snails, worms, corals, protozoa, and so on.

Let me give a very brief account of the history of the vertebrates. The earliest forms which have left fossils lived in water some four hundred million years ago. They were somewhat like fish, but they had no paired fins and no lower jaws. Instead of eating like modern fish they sucked in mud and filtered it through a series of holes on each side behind their mouths. The water and finer particles escaped through these holes. Though they had eyes, their life was not very unlike that of earthworms. A few of their descendants, living this kind of life, survive to this day.

The filter had a supporting skeleton of cartilaginous bars. About 350 million years ago or a little earlier a joint developed in the first of these bars, and it became a pair of jaws. They could now eat larger objects,

including, no doubt, the molluscs and crustaceans which lived beside them. At about the same time they developed paired fins, and were able to swim much like modern fish. In a few tens of millions of years there were very many different species of fish. Some had three or more pairs of fins, but only those with two pairs survived, and became our ancestors and those of modern fish, birds and four-legged animals. If the six-finned forms had been more successful we might have wings and arms like an angel, or several pairs of arms like a *deva*.

During the Devonian period, about 320 million years ago, most geologists think that there were many shallow lagoons which dried up from time to time. Some of these fish could only survive if they could crawl out of pools which dried up. They developed jointed fins like those of the mud skipper which lives today on the coasts of India. They also used their swim bladders to breathe air, as the *māghur* and some other Indian fish do today. The jointed fins were transformed into stumpy legs, and they began to eat land plants or insects. We have got fossils illustrating various steps in the process, notably of an animal with four short legs but a fish tail.

These first four-footed animals were amphibians shaped much like lizards; but, like frogs, they had to go back to the water to lay their eggs. Some time in the carboniferous period, 300 million years or so ago, some of these animals started laying closed eggs on land. Either two groups achieved this independently or they diverged very soon. One group, which later became the ancestors of mammals, were the biggest land animals for about eighty million years. Then they nearly died out, and for a hundred million years the lizard-like and bird-like reptiles dominated the earth. Some were larger than elephants, others smaller than mice. Many walked or ran on their hind legs. Two groups took to the air, first the pterosaurs with wings like bats, and later the birds. One group took to burrowing, lost their legs, but later emerged again to become the snakes. Another shut themselves up in armour and became tortoises. At least five groups went back to the sea, though they continued to breathe air. A hundred million years ago there was perhaps a greater diversity of air-breathing vertebrates than today. The fish also evolved to forms more like the modern types.

Then, about 80 million years ago a surprising and so far quite unexplained event occurred. Over a period of twenty million years or so, most of the reptilian groups died out, on land, sea, and air. Their places were taken by mammals, fish, and birds. At first the mammals were not very diverse, but for 70 million years they evolved in many different directions. As regards form they have been less enterprising than the reptiles. None of them are as strange as snakes or tortoises, though an extinct South American group shut themselves up in armour like tortoises. The most original group was perhaps the elephants, which, five million years ago, had spread over the whole world except Australia, Antarctica, and most islands.

Three tragic events have reduced this wonderful diversity. About five million years ago, South America, which had been an island, was joined to North America, as it still is. Northern mammals conquered it, and killed off most of the local forms, some of which had been very beautiful. A million years or less ago, a series of ice ages desolated much of the world, and killed off many species. Finally men evolved and went through a phase of at least a quarter

of a million years during which they lived mainly by hunting animals. Even when they domesticated a few species they wiped out others. The invention of firearms speeded up this process, and tropical Africa, which had been spared by the ice ages, was desolated by men. We are at last realizing that we have a duty to preserve what is left of this diversity, and Indian Governments are doing their best to save the lion and that much more interesting beast, the rhinoceros. I leave it to moralists or theologians to determine why we have this duty; I am only convinced that we have it.

We see that the acquisition of new powers led to increases of diversity. But with the advent of men this tendency was reversed. To a biologist one human being is pretty like another. They differ greatly in their behaviour and intelligence, and this introduces a new kind of diversity, of which I will not speak here. The history of insects, particularly the social insects, may prove even more interesting when we know it in as much detail as we know that of the vertebrates.

Why are the insects so vastly diversified? You will remember that there are a million or more insect species. I shall suggest one reason. Insects have minds, in my opinion,

and I shall try to show in my next lecture that some have fairly highly developed minds. But they have very much more standardized behaviour than mammals or birds. Western zoologists write of instinct. Perhaps *svadharma* is as good a word for describing the fact that a species of insect may feed on a single species only of plants or animals. For example, there are three species of lice which feed only on men, and their behaviour adapts them to feed on men alone. So very many species are needed to carry out these diverse behaviours.

Some 2,10,000, or two lakhs, of species of flowering plants are known. These include all the familiar land plants except ferns and mosses. I doubt whether as many as 20,000 species remain undescribed. It is interesting that about one-tenth of all these species are to be found in India. States with much larger areas, such as the Soviet Union, have fewer species. The only State with a greater diversity of flowering plants than India is Brazil. Britain, for example, has only about 1,200 native species.

Islamic and Christian scientists who believed that the world had been created less than 10,000 years ago naturally thought that

each species was due to a separate act of creation. Ancient Indian thinkers put forward the notion of *pariṇāmā*, transformation, but the modern idea of evolution is rather different from this. It was first seriously developed by Lamarck in France, but Darwin first persuaded the majority of biologists of its truth. Though Darwin gave a rational explanation of how it occurred, an explanation which I think is largely correct, one can accept evolution as a historical fact without believing that natural selection was the main evolutionary agency. Similarly one can believe that Ajātaśatru defeated the Licchavis without believing either that he was helped by *devas* and *asuras*, or in Kosambi's recent Marxist explanation.

There are two main lines of evidence for evolution. One is from fossils, the other from genetics, that is to say the actual breeding of living plants and animals. The fossil record is very incomplete for some simple reasons. The earliest rocks with adequately preserved fossils are about 55 crores of years old, though there are earlier fossils, and life on earth may be twice as old. Large tracts of the earth's surface have no fossils, for example the Deccan is largely made of consolidated volcanic lava. Other

tracts, such as most of the Ganges basin, are covered with very recent deposits. There may be most interesting fossils in the rocks under Lucknow or Calcutta, but these rocks are a long way down. If all different ages in the last 500 million years were equally represented, the rocks formed in any particular million years would be found on about a thousandth of the earth's surface. In fact, some stretches of many millions years are hardly represented at all, the older ones being usually rarest. Also many animals and plants have no hard parts, and are hardly ever represented as fossils, while others, such as insects, are much less likely to be preserved than animals with shells or bones.

Nevertheless, we have enough layers of clay and rock deposited continuously over millions of year to show that some species changed slowly and steadily, the change being so great that if the forms, living at different times, were found alive today they would be assigned to different species. The best evidence of this kind is from molluscs, particularly the coiled sea molluscs called ammonites by biologists, and *Śaligram* in India. For a few living animals, such as horses and elephants, we have enough fossils

to be fairly sure of their ancestry. For others, such as men, the gaps are much greater; but there are plenty of skeletons with heads smaller than those of men, but larger than those of animals of the same body size, and intermediate in other respects.

Popular accounts of evolution are a little misleading for several reasons. One is that they do not emphasize its slowness. As you know, horses have very peculiar teeth, adapted for grazing grasses which wear them away. As we look at the teeth of the ancestors of horses over the last fifty million years we see that the oldest of these had short teeth like men or pigs, and that they gradually got longer. The average increase was 3 or 4 per cent per million years. In a wild animal population about two-thirds of the tooth lengths are within 5 per cent of the average. So we should have to go back three million years or so to find a population which did not greatly overlap the modern one.

Another fallacy is that evolution has generally been progressive, descendants being more complex in structure and behaviour than their ancestors. I should think that for every case of progress in this sense there had been ten of regressive evolution. For example, birds are probably descended from a

single species which first achieved flight. But many birds have lost the capacity for flight, the best known being the ostrich. Similarly many species of fish have taken to living in caves and lost their eyesight. Evolution has on the whole been progressive because a species which acquires a new capacity may give rise to many descendants which exploit it in different ways, while one which loses it is far less likely to do so.

Fifty years ago it was thought that the differences between different breeds of dogs poultry, or peas, though striking, were superficial, because they will all mate and give fertile hybrids, while, for example, dogs and foxes will not. We have now been able to make barriers to interbreeding within a species, and even made new species. And rapid, though small, evolutionary changes have been observed, for example the blackening of about seventy species of moth in the industrial areas of England. In one case, Kettlewell has shown conclusively that this change was brought about by natural selection. So most, though not all, biologists believe that the differences between members of two different species are of the same kind as those between members of the same species, though there are many more of them.

We have a fairly good history of the evolution of the vertebrates, and a less complete one of that of the insects, the two most advanced groups of animals. The earliest vertebrates and insects, four hundred million years or so ago, were very simple creatures not very unlike members of other groups. There is little doubt that all the living species of insects or of vertebrates are descended from one or a few species living at that time. As Professor M. R. Sahni and others have pointed out, the animal *avatārs* of Vishnu give a rough idea of the most advanced vertebrates at various times in the past. Three hundred and fifty million years ago the most complicated vertebrates were fish, two hundred and fifty million years ago reptiles, though the tortoises are well off the line of human ancestry. Sixty million years ago they were four-footed mammals not so very unlike boars. Fifteen million years ago they had some human characters like *Narasiṁha*, and only a million years or so in the past they were short erect dwarf species much more like men than any monkeys, but not quite human.

Just as the fish are the oldest group of vertebrates, the locusts and similar animals are the oldest surviving order of winged insects.

We know less about plant evolution, but the flowering plants are only about 150 million years old (possibly rather less) and even the ferns not much over 300 million. I give these dates with some confidence, for rocks can now be dated with fair accuracy by the products of radioactivity which have accumulated in them.

However, many groups of sea animals such as molluscs and echinoderms (sea urchins, starfish, and the like) were in existence 500 million years ago, and have not made very great progress since. What can we say about their origin ?

Three branches of biology confirm and supplement the history of evolution as revealed by fossils. One is comparative anatomy. The more like two animal species are in their anatomy the more recent, as a general rule, is their latest common ancestor. For example, externally a crocodile resembles a cow more than it resembles a bird. But the hearts, and many other internal organs, of birds and crocodiles are fairly similar, and in fact their latest common ancestor lived about 200 million years ago, and that of the cow and crocodile about 300 million years back. So we can use comparative anatomy to work out relationships where we have

no fossils. To take an analogy, Hindi and Italian are only moderately similar, but their ancestors, Sanskrit and Latin, are much more so. No doubt Sanskrit and Latin are descended from a common ancestor in the remote past. If we had no records of past languages it would be a hazardous guess that languages had evolved as we know they have. But given our knowledge of Sanskrit, Latin, Hebrew, and other ancient languages, we can confidently trace family relations between African languages, and even reconstruct ancient ones to a slight extent, though there are no records of ancient languages in most of Africa. So we can be fairly sure that insects, centipedes, spiders, crabs, and barnacles had one common ancestor, snails, oysters, and cuttlefish another, and so on.

Comparative embryology tells us a similar story. The early stages of development of related animals are often remarkably alike. So are those of animals with no obvious likeness when adult, for example molluscs and annelids, the group of worms which includes earthworms and leeches.

The simplest animals are single-celled ones. Most of these live in soil and water and are harmless. But a few are parasites, causing such serious diseases as malaria and

amoebic dysentery. They are generally thought to be ancestral to many-celled animals. The sponges, which are barely animals, probably represent one line of descent from them, and all other many-celled animals another. The simplest many-celled animals are the coelenterates, such as jelly fish and corals, and they have generally been thought to be primitive. However, a Yugoslav biologist called Hadji is putting forward the view that flat worms are primitive, and coelenterates degenerate.

Yugoslavia has not produced many scientists, but those whom it has produced think for themselves, as do its politicians. Mohorovicic, from measurements of the speed of propagation of earthquake shocks, produced a theory of the layers in the earth's crust which is universally accepted. Milankovic has produced an astronomical theory of ice ages which has probably lost favour in the last ten years, but still may be true. Zupancic's theory of hormone action has not met with much approval, but may also be true. Fifty years hence Hadji may be thought the greatest zoologist of his time, or he may be completely forgotten.

Such questions will, I believe, be decided by the findings of a third branch of biology,

namely comparative biochemistry. Animals which are alike in structure tend to be alike in their biochemistry. You know this, but perhaps you don't know that you know it. You probably take it for granted that vertebrate animals have red blood, and other animals have not. In fact a few Antarctic fish have transparent blood. And haemoglobin, the red blood pigment, is found in a few insects, snails, and worms, and in a few plant roots. So the vertebral column is a better criterion for classification than red blood. But the colour of blood is a good guide to relationship.

We are just beginning to make similar observations on colourless substances. For example, an important, though secondary, source of energy for the contraction of vertebrate muscles is creatine phosphate.

Among the invertebrates this has been found in a worm-like animal *Balanoglossus* and in some echinoderms, but not elsewhere. This confirms the findings of comparative anatomy and embryology that these groups are related to the vertebrates.

But the most surprising result of comparative biochemistry is the extraordinary likeness of the make-up of the living material in all plants and animals, and of the chemical

changes which go on in it. The parts of living organisms which are perhaps best regarded as not living, such as bones, shells, wood, tendons, vegetable fibres, and so on, are much more different. For example, human blood contains about one part in a thousand of a sugar called glucose which is used by the every organ in our body. It is found in the sap of many plants. Other plants contain cane sugar, a compound which is easily split into glucose and fructose, the sugar found in the sperm of mammals. The chemical processes yielding work are apparently the same in all living beings. Look at a bullock walking round, pumping water from a well, and a palm tree beside it. The tree is pumping water too, though only at a speed of a few feet per hour. If it stopped, its leaves would soon wither. The immediate source of energy for beast and tree alike is almost certainly a compound called adenosine triphosphate. It is also the source of light in fireflies. In fact the most delicate test for it is to add water containing it to an extract of fireflies and watch for flashes through a microscope. The energy needed by bullock and palm alike to make fresh adenosine triphosphate is provided by a series of chemical reactions

which only differ in minor details. J. C. Bose's belief in the fundamental unity of plant and animal life has been fully vindicated.

In fact, most of the vital processes in animal and plant cells are very nearly the same, though the cells are specialized to do very different functions, and arrange themselves in very different forms. These similarities, and others of which I shall speak later, are readily explained if all living beings are descended from the same common ancestors.

I have been asked to speak about the origin of life. To weigh the alternative possibilities and state the evidence for them however briefly would take me another hour. I personally think that there is no sharp line between living and non-living matter. To know why I think so there is no need to talk about viruses such as those causing smallpox and influenza, which some think are alive while others do not. Think of an atom of carbon in a molecule of rice starch which you eat. When it is in your mouth or stomach it is inside a living system but hardly part of it. Even in your blood it is not really incorporated into you. It is taken up by the liver, later passed through the blood to a muscle,

and so on. It may be built into the contracting substance and be part of it for some years, or unite with oxygen and pass away in your breath as carbon dioxide. No one can say just when it begins and ceases to be part of a living system, though there is no doubt that it is so for a certain time.

Similarly even if we knew much more than we do about the past, we might not be able to say just when certain kinds of matter became sufficiently organized to be called alive. There is very little free oxygen in the air of the other planets of our solar system; and the main source of it here is from the dissociation of carbon dioxide by plants with the help of sunlight. So probably the earth's primitive atmosphere contained no free oxygen. If so, many of the chemical compounds needed both as energy sources and building materials accumulated in air water, and soil. They were gradually broken down again to stabler forms. Whereas now they would be very quickly used up by plants and animals as food.

Systems which convert stored chemical energy into heat and movement often acquire some kind of organisation which preserves their form for a certain time. The best known examples are flames. Also some

kinds of molecule attract others of the same kind to form organized aggregates such as crystals. The question whether these very primitive kinds of organization of material processes and objects were able to develop into the much more complex organization which we call life is not at present answerable with any certainty. I have recently discussed the matter in some detail, pointing out in particular some scientific and mathematical questions which are answerable without too great difficulty, and whose answer would at least tell for or against this theory. If it is rejected two other hypotheses are compatible with the common ancestry of all living beings on this planet. One is that matter and life are both eternal, but life can only arise from life, and the first living being reached us from another star. The other, which Darwin suggested, is that life is due to a single creative act by a supernatural being, rather than many separate acts, as is the doctrine of some religions. I personally incline to the view that living beings arose on our earth by a natural process.

A conference on this topic has recently been held at Moscow. It dealt largely with detailed facts about the chemistry of earth, sea, and air, the synthesis of organic com-

pounds by non-living agencies, and the workings of existing living things which are relevant to the discussion. There is no doubt that men will try to make life. If this is possible it may demand a technical and intellectual effort as much greater than that involved in launching the *sputnik* as that effort exceeded the effort needed to make the first bow which would send an arrow for fifty yards.

II

YESTERDAY, I gave what seem to me good reasons for believing that all living beings are descended from a common ancestor. When we say, metaphorically, that all men are brothers, we mean, among other things, that they have common ancestors. We also mean that they are alike in their mental processes, and that therefore they have similar rights and duties.

If we say that all men are brothers, we can say that the animals and plants are our cousins, though rather distant ones. I think it is probable that if a man or woman who lived 1,00,000 years ago is the ancestor of any living man, he or she is the ancestor of us all. To find a common ancestor for a man and an insect we should have to go back about 7,000 times as far into the past; so the insects are pretty remote cousins. But does the metaphor mean any more than this? Can we find evidence that animal minds are like human minds? I shall try to show you that we can; I shall even try to convince you that the sexual reproduction of plants involves emotion.

We cannot prove that animals are conscious. But then I cannot prove that you are conscious. However I believe it. I also believe that a cow or a bird is conscious. We can however prove that animals have behaviour which we call moral or social when we find it in men. Marriage is one of the most fundamental of human institutions. It is found in all societies, though its forms vary, and most of us think that the kind of marriage prevalent in our own society is the best kind. Does it exist in animals? I define marriage as the association of a male and female, for economic as well as sexual purposes, *artha* as well as *kāma*, preceded by a ceremony, and normally lasting at least until the children no longer need parental care. Clearly many animals do not marry in this sense. But even so some elements of human marriage may be found in unexpected quarters.

In my laboratory in London we used to breed a little fly, *Drosophila subobscura*, weighing less than a milligram. That is to say, 10 crores of these flies would weigh as much as a man. If you put a male and an unmated female together in a small glass tube they soon meet. The male stands in front of the female, and flicks his wings in

a characteristic way. She then begins to dance with rapid movements to right and left. If the male can follow her motions and remain facing her for a minute or so, they usually kiss with the ends of their proboscides, and the female permits mating. But many males cannot dance adequately, and are kicked off if they try to mate.

In this species a female will never mate again on the same day. If she has not begun to lay fertile eggs she will mate again next day. But if she has once started laying fertile eggs she will hardly ever mate again, even after thirty days, which is about the equivalent of thirty years of human life, for these flies usually live more than a month but rarely as long as three months. The males, however, show no such fidelity. Clearly we have here some of the elements of marriage, but not perhaps the most important.

Marriage is seen at its best in birds. Our small English song birds have a fairly general pattern. Early in the spring a male bird occupies a territory by singing vigorously along its boundaries, and perhaps occasionally fighting intruding males. Females listen to the song, and look at the male and his property. If the female flies away the male does not chase her. If she stays he makes

various songs and postures to the female and gives her food. This is often called courtship, but as we shall see, this phrase is misleading. After a period which is often of several weeks they build a nest. Usually both spouses build, but the hen may do it alone. When the nest is finished, the birds mate. But this does not generally occur till they have known one another for a month or so. When the eggs are laid the male may or may not help to keep them warm by day. He almost always does so at night. And he usually helps to feed the children when they hatch. During all this time of active family life the male generally continues to dance in front of the female and give her food. Some water birds give one another little presents of water weed which they do not eat, but seem to enjoy. As J. S. Huxley first pointed out, this behaviour can serve as courtship, but it also keeps a mated pair together and stabilizes the marriage. So, of course, does comparable behaviour in human beings.

Most of our small British birds are monogamous. But Mr. Salim Ali tells me that an industrious male Indian weaver bird may make several nests, and induce a different wife to live in each of them. The ladies do

not, apparently, meet, so there are no quarrels between them.

Small European birds are mostly short-lived. Thus only about half the adult starlings (a bird similar to the mynah and of about the same size) living today will be alive in December of next year. Hence a survivor is as likely as not to be a widow or widower next year. So these small birds commonly marry afresh in each year of their lives. I do not shoot birds at any time, but it seems to me much worse to shoot ducks during the part of the year when they are married than during the remainder of it. A duck is certain to die some time. It may escape the sorrow caused by the death of its husband or wife. If you have ever watched a pair of ducks on a tank searching for one another after a few minutes' separation, you will hardly doubt that it is real sorrow.

Larger birds commonly marry for their joint lives, and it is not rare for widows or widowers to refuse to marry again. Some European species of lizard behave in this way. The widows, and particularly the widowers, attack other members of their species pretty savagely.

Mammals do not furnish such good examples of monogamy. They tend to group themselves in units larger than the family of two parents and their children. This is of course a step towards the evolution of society, but it is hard to reconcile it with monogamy. So we find the nearest approaches to the human ideal of marriage among not very social mammals such as tigers. This does not however mean that other wild mammals are quite promiscuous.

Now it is curious that in popular speech, at least in Europe, such words as "animalism" are used to mean sexual promiscuity. I think this is because few of our domestic animals are monogamous. The most nearly monogamous is the domestic pigeon. But there is no doubt that domestication has corrupted our cattle, sheep, and so on. A bull who will not mate with any cow or a cow who will not mate with any bull is likely to be killed in Europe. Even in India it will not be much used for breeding. So there is heavy selection against animals whose conduct approaches that of which we approve in men and women.

Now I want to defend fish. A few species of fish, especially of the family *Cichlidae*, contract marriages after a fairly elaborate

ceremonial courtship, and are usually faithful when offered a further choice of mates. This kind of behaviour is almost confined to fish living in lakes or slowly moving rivers, for a very obvious reason. A pair once separated in the ocean, or in a quickly moving river like the Jumna, are unlikely ever to meet again. In still water they may have their home in a bed of reeds, and learn their way back to it. Such fish do well in an aquarium provided one can find them mates whom they accept.

These still-water fish often look after their children. At the Fisheries Research Station at Cuttack I was shown a pair of *Tilapia mozambiquensis*, a fresh-water fish of African origin which is bred in tanks in Indonesia, and whose introduction into India is being considered. One of the workers poked a fish with a stick, and it immediately spat out a hundred or so of its children from its mouth. If it had been caught, they might have escaped. It later took them into its mouth again, where of course they would have been safe from other fish. In some species both father and mother may protect their young in this way, and the parents' throats are often blocked by a growth of flesh after breeding, so that they

cannot swallow their children accidentally. Casual observation of such fish has given rise to the legend that they breed from their mouths.

Other fish, for example *Colisa*, which is quite common in Bengal tanks, look after their young as follows. The male and female blow bubbles among the water plants. When the nest of bubbles is ready she lays eggs in it, and he fertilizes them. The father then guards this nest against animals which might eat the eggs, and when the young have hatched he guards them for some time.

Many fish move in shoals, and thus have at least a rudimentary social organisation. There is no evidence as yet that bees or other social insects can recognize other individuals, though they can tell a member of their own hive from that of another by its smell. But fish can do so. Goz trained a small fish to come for food when water, in which one and only one of twelve others had been swimming, was put into his jar. That is to say he knew other fish as individuals. This may be a basic difference between insect and vertebrate societies. And it is, I think, another refutation of *matsya nyāya*, and an argument in

favour of those who object to killing and eating fish.

I have shown you, then, that some animals are models for human moral behaviour. We may say that their conduct is instinctive, not moral, behaviour. Perhaps the animals feel no desire to leave their spouse or eat their young. So much the better. We do not take human conjugal fidelity for granted. We do take it for granted that parents will die of hunger before eating their children, and we should severely blame any who ate them. It is not possible to draw a sharp line between instinctive conduct and moral conduct. But someone may say that even if animals have laudable instincts, they have nothing like human intelligence, and in particular nothing like human language which requires intelligence to use.

I have heard various public speakers speak of the great scientific discoveries of this century. In every case they referred to discoveries about the fine structure of matter, and usually drew the moral that they had been misused to make atomic bombs, and so on. I think that only two of the discoveries of this century in physics are of profound philosophical importance. One is Einstein's discovery that time and space

are aspects of the same kind of relationship. The other is that the distinction between two particles of the same kind, such as electrons, is not absolute. We have not yet got the words to formulate this principle adequately. But it helps me to believe that the distinction between you and me, or the nearest mosquito and me, is nothing absolute either.

However, in my opinion the scientific discovery of the greatest philosophical importance was made by von Frisch. He discovered that hive bees have a language, and managed to understand at least some of it. His work was done on European bees, and as their languages differed slightly, there is little doubt that those of Indian bees will be found to be still more different. What I shall tell you may not all be true of Indian bees.

A beehive is a family whose mother, the so-called queen (but perhaps goddess would be a better metaphor) may live for some years. The workers only live for about six weeks in summer. The first three are spent on duties in the hive, the remainder in gathering food, and occasionally water and a kind of cement which is used in building. The foraging bees fall into two classes. About

one in twenty looks for new sources of food; the others go where they are told. As all the bees in a hive are usually sisters, we do not know how the distinction arises.

If a bee has found a plentiful source of food, whether in flowers or in a dish of scented sugar water offered by a professor, within 50 yards of the hive, she flies back and dances round and round on the vertical surface of a honeycomb. Other bees follow her, smelling her back with their antennae. If they are accustomed to visit flowers with the odour which they find on the dancer, they fly out in all directions and look for a flower with this smell. A few may change over to a new flower, or fly out for the first time. These facts were discovered by marking individual bees with tiny spots of lacquer, and using a hive with a glass window. As soon as this was done, von Frisch found that, although a hive looks very busy, each individual bee spends a lot of time resting or gossiping with others. Few work for more than eight hours a day.

If the food is several hundred yards away the dance is quite different. It consists of straight runs in a certain direction, ending with a turn to right or left, and another run along the same path. During the run the bee waggles her

abdomen. These dances were described by the Greek philosopher Aristotle 2200 years ago, but it was von Frisch who discovered that they were a language.

If the straight part of the dance is vertically upwards, this means that the food is in the direction of the sun. If it is 30 degrees to the right of the vertical, it means that the source is 30 degrees to the right of the sun, that is to say, in the northern hemisphere north of the tropics, usually to the west of the sun. The distance is signalled in two ways. The number of turns per minute goes down as the distance increases; and the number of abdominal waggles in each straight run increases by about one for each 75 yards of distance. However what is communicated is not distance, but time or effort. For the dance is slower, and more waggles are made, when the food source is up the wind or uphill.

How accurate is this signalling? The bees spread out a bit round the direction signalled, but the centre of the various directions is usually correct within two or three degrees. This means that the bees' communication is more precise than such a human phrase as "north east by north", but not so accurate as "17 degrees east of

north". The distance is apparently judged correctly within 5 per cent or so. This again is very good by human standards. How many of you would say that a house is 530 yards along the road? You would be quite content if you had said 500 or 600 yards.

But the most startling discovery of all was made by von Frisch's pupil Lindauer. When a hive becomes over-populated, some of the bees leave it, usually with the old queen, while one of her daughters replaces her. The swarm may hang on a branch for several days. Bees fly out from it looking for a site for a new hive. When they have found one, perhaps in a hollow tree or in the roof of a house, they report back and signal the direction and distance by dancing on the swarm. Other bees fly out, and if they are satisfied, they signal the location to others. A bee may change its mind, or, if others do not agree with it, may retire from politics into the middle of the swarm. Lindauer gives the records of several debates of this kind which lasted for more than a day. Usually unanimity is reached. But a swarm may split in two. If so the goddess goes off in one half, and the others follow her later.

This is, I think, a really great discovery. Here is a highly organized community with no private property. It is a socialistic society. But it is not a dictatorship or tyranny ruled by one individual. Nor does it show any signs of being ruled by a group soul, as theosophists hold. On the contrary there is a diversity of opinions, and one of these finally prevails not by violence but by persuasion.

There are certainly other means of communication in the hive, including at least one by smell, but apparently no sounds. We do not yet know, for example, how bees co-operate to make the honey cells with the beautiful precision which is achieved, how they decide to swarm, how they regulate the temperature by bringing in water in hot weather, and many other things.

If bees observed human beings they might report something like this: "These large creatures are clearly very stupid, and have no real language. Many of their dances are crudely erotic. However, in Southern India some precision has been reached. But even here the *mudrās* appear to signal emotions rather than facts. There is not the faintest evidence that they can communicate either direction or distance."

By the way, you will have noticed that the two examples which I have chosen to demonstrate the similarity of animal and human minds both refer to social behaviour. This is not accidental, and is of some philosophical importance.

Please do not think I am arguing that animals are better or more intelligent than men. Some of them are better in some respects. But if the distinction between good and evil has any meaning, I do not think we can avoid the conclusion that some animal and plant species are evil. Parasitic worms, for example, cause the slow and often painful death of animals, including men, in which they live. And they have themselves lost the nervous system and sense organs which their ancestors almost surely possessed. Whereas the tiger, for example, kills quickly, and possesses beauty, intelligence, maternal love, and other good qualities. If we are to speak of the unity of life in the sense that we apply human criteria to other animals, we shall certainly find evidence of evil as well as good throughout the living world.

I consider it most important that Indians should take up the systematic study of animal behaviour. It can be of economic

value, but I am thinking of its cultural value. In the past, Indians have been almost alone in refusing to eat animals, providing hospitals for sick animals, and so on. It is not my business to defend such attitudes. But I can say that they are very much more easily defended if they are based on scientific facts discovered in a careful study of animal behaviour. You have a few great observers of wild animals, such as Mr. Salim Ali. There is room for thousands more. In particular the study of Indian bees requires no expensive apparatus. We know that they dance. We know very little more. In a country where the sun can be overhead it is hard to use it as a compass. But Lindauer found that bees in Ceylon could recognize a deviation of the sun from the zenith which he could not. In other words, though their eyes are not so efficient as ours, the *indriya*, or as I would put it, the nervous analyser, behind them, is more efficient.

Now I want to pass to another aspect of the unity of life, the co-operation between different species. The antagonism is obvious enough. Animals eat one another, besides eating plants. But the co-operation is usually between very different kinds of organisms. I shall just give two examples.

When we speak of a rat we are apt to forget that the rat includes crores of bacteria with independent lives of their own, which live in its intestine. However it is possible to rear rats aseptically, with no bacteria in them. At most the bacteria provide some substances of which there may be a shortage in the rat's food. Probably a man could get on without bacteria, though again he would have to see that his diet was complete in certain respects. But a cow or a horse could not live on anything like their normal diets without bacteria and protozoa. A cow can live on grass. You and I cannot. Her digestive juices are not very unlike ours, but her stomach has several compartments, in some of which there are various kinds of single-celled organisms which help the cow to digest plant material which she could not use without them. Incidentally, they produce the pleasant smell which characterises the breath of a healthy cow. She spends a lot of time chewing the cud which she brings up from her stomach to her mouth, thus aiding the protozoa and bacteria in their work. Similarly, termites (white ants) cannot digest wood, but they contain protozoa which can do so.

We are much too apt to think of protozoa and bacteria as responsible for diseases such as malaria and cholera. Most of them are harmless. And they play an essential part in the cyclical changes which matter undergoes in the community of living organisms by converting dead plants and animals into chemical substances which the higher plants can absorb from the soil and make once more into living substance.

It is one thing to have one's digestion done for one by organisms of another species. It is much more remarkable to use another species to feel one's emotions. But consider flowers for a few minutes. They contain the sexual organs of plants. In the centre we usually find the stigma, a slightly moist surface which is the female external sexual organ, at the end of a pillar called the style. Round it are the male organs, the stamens which produce the pollen. When pollen is carried to the stigma the pollen grains burst, and microscopic tubes grow down from them into the female style, and finally fertilize the ovules in the ovary below it, which then become seeds. However the most conspicuous parts of a flower are usually the petals, which are commonly brightly coloured and highly scented.

There may also be nectaries producing a sweet fluid. Every flower is a sexual symbol.

Many flowers are self-sterile. Pollen from any one plant will not produce seeds on any of the flowers on it. What is more, a self-sterile plant is generally a member of a *gotra* no members of which can be crossed with other members. I use the word *gotra* not out of condescension to you, but because there is no English word for such a group. Membership of a *gotra* is determined both by the mother and father, and the discovery of the rules by which this is done was one of the most beautiful achievements of genetics. Even when plants are self-fertile they usually yield more seed, and more vigorous seedlings, if they are pollinated from another plant. This pollination is usually done by insects, which are attracted to flowers both by their colour, their form, their odour, and their experience that they are sources of food.

Bees, butterflies, and many other insects are attracted by the bright colours of flowers and their regular shapes. A lot of work has been done with paper models, synthetic scents, and so on. It is clear that the aesthetic tastes of these insects are not very unlike our own, though bees can distinguish colours

invisible to us in the ultraviolet, and cannot see red (or more accurately cannot distinguish it from dark grey). The vegetarian birds, or at least some of them, share these tastes. Other groups of animals have very different aesthetic preferences.

When a bee visits a flower, it finds certain colours, shapes, and odours satisfactory. It may also drink the sugary secretion of the flower, the so-called nectar, or gather some of its pollen to store in the comb. If it then visits another flower of the same species, it may leave some pollen in it, and cause a sexual union of the two plants which engenders one or more seeds. We may say that the love of the plant is the bee's aesthetic emotion, the lust of the plant is the bee's hunger. This point of view should not, I think, be quite novel to those who have read the *Yoga Vaśiṣtha* or the philosophy of Josiah Royce.

If a long-lived celestial being had visited our planet once in every ten million years or so, he would have seen the first trees some three hundred million years ago. They were like our tree-ferns, pines, and so on, and the herbs beneath them not unlike our ferns. The fertile parts of our planet were a rather monotonous green. Then in the

Jurassic period, about 150 million years ago, flowers appeared, though they were at first very unlike most modern flowers. They became useful to the plants because of the psychological evolution of insects. The earth had put on new colours because there were at last animals which could appreciate them.

Somewhat later many plants developed fruits with bright colours and smelling not unlike the flowers. The birds and mammals ate them, but often carried the seeds for some distance. Thus although the plants cannot move, they can use animals, first to enable plants at a distance to mate with one another, and later, to allow their children to travel, and find new places to grow. It is not quite a metaphor to say that the monkey's pleasure in eating fruits is the mother-love of the fruit tree. All this co-operation is of course shot through with evil, or at least what appears to us men as evil so long as we can use this word meaningfully. Insects, for example, may eat the fruit without transporting the seeds. But it is nevertheless true that for a hundred million years or so the ancestors of the human race seem to have been co-operating with some of the higher plants, eating some of their

fruits and seeds, and scattering others. Of course this co-operation was unconscious. As soon as it became conscious, agriculture started. But there had been a long preparation for it.

By the way, please don't think that no animals practise agriculture. Some Brazilian ants collect leaves which they take underground into their nests, and on which they plant a fungus which they eat. Each winged female who flies out, and may become mother and goddess of a new nest, carries a little of the fungus in a pocket near her mouth, and plants it if she founds a nest successfully.

What I have said to-day may seem to you very subjective. It is certainly my own point of view, and others will not agree with it. But it is based on a study of biology over some sixty years, largely a study of what a philosopher might consider minor details, such as the shapes of bones of extinct animals, the chemical composition of my own blood, the inheritance of flower shape in primroses, and the ascents of koi fish for air. Without such studies one is not well qualified to form an opinion. If I wished to make a new translation of Kālidāsa's works into English, my first task would be an intensive study

of the details of Sanskrit grammar. My next would be, not merely to read the texts and translations of them, but to discuss them with pandits who had special knowledge which I lacked.

I am afraid that I am not always as polite as I should be to people who propound a philosophy o life after reading a few popular books on biology.

What India needs, from a cultural point of view, is careful and loving observation of Indian animals and plants, preferably while living under natural conditions. I am glad to see signs of this around me. To take just one example, this year Dr. Roonwal, the Director of the Zoological Survey of India, has reported his observations on the behaviour of wild bees during a partial solar eclipse to the Indian National Institute of Sciences. This means, among other things, that young zoologists who observe animal behaviour need not despair of obtaining posts in the Zoological Survey.

III

A LITTLE OVER a hundred years ago microscopists discovered that most of the living tissues of plants and animals are divided up into cells. These are rather small. The diameter of a representative human cell is about a fiftieth of a millimetre, or under a thousandth of an inch. However there are about as many atoms in a human cell as cells in a human body. So a cell is a very complicated being. In the last fifty years it has been found that a single cell can live and reproduce when separated from the rest of the body. It requires very careful treatment, including the provision, for the cells of men and higher animals, of various chemical compounds found in the blood, in just the right quantities. The best proof of the independence of cellular life is that such a tissue culture, as it is called, may go on living long after the animal, plant, or human being from which it was taken has died.

The progeny of a single cell from a man or higher animal may organize themselves into a tissue which carries out some physiological functions. Thus cells from the heart of an

embryo chick formed mats of tissue which went on contracting rhythmically for many years. In some plants and simple animals the cells descended from a single cell can regenerate a complete new animal or plant. Those of many animals and plants are too specialized to do so, with one most important exception.

Every cell includes a nucleus, and this nucleus contains materials which are accurately copied when the nucleus divides; but at other times the atoms in them are much less frequently replaced by new atoms from the food than are those in other parts of the cell. Most of the hereditary characters of living things depend on this portion of the nucleus. It consists in part of what are called genes, which control different processes, for example, the production of colouring matter in flowers, animal hair, or silk, or the growth of horns in cattle or awns in rice. Genes also determine the needs of a plant or animal. Some rice plants will only grow well in deep water; no British cattle will thrive in Indian hot weather. The aggregate of the genes is called the genome. It might be called the *svadharma*, for it determines the needs of a plant or animal, and its possible performance.

Sexual reproduction involves the formation of special cells called gametes, each of which has lost half its genome or *svadharma*. A small cell of this kind produced by a male penetrates a larger one produced by a female. They constitute a new cell with a complete *svadharma*, which then divides, grows, and becomes a new plant or animal. Sometimes, as with most fish and frogs, this union takes place in water. More usually it takes place inside the mother. The embryo may be born at once before it is properly formed. Or it may be nourished by the mother for a long time, and only start independent life when it has reached a considerable size, for example a calf or a coconut.

I have tried to compress into five minutes the main results of some centuries of work by tens of thousands of men and women. Obviously they raise the most profound philosophical problems on some of which I will touch later. Let me raise just one now. A cell is certainly alive. Is a gene alive? I lost my hair before I was thirty because the cells in my scalp contained a gene causing premature baldness which can either be called a descendant of a similar gene in my father, or a remote but accurate copy of it. Let us consider a parallel case. One learns the

Gāyatri Mantra from an older man, who learned it as a boy. It has been transmitted by copying in this way for at least a hundred human generations, perhaps many more. But it has also been said to be a goddess with a life of her own. Both these statements seem to me to have an element of truth, though I do not believe the second literally.

Probably the most surprising fact about genetics is that some principles hold both for plants and animals. Most of the principles discovered by Mendel in his study of the pea can be applied to animals. Linkage, which enables us to locate genes on chromosomes, was first discovered in plants, and only later in animals, including human beings. Only three years ago my wife was able to study for the first time the inheritance of characters when an animal is self-fertilized, and found that it was precisely the same as with self-fertilized plants.

This similarity is due to the remarkably similar organisation of the nucleus and particularly of its division in most plants and animals. It is not the only possible organization, for a few plants and animals have a rather different one. And in bacteria the organization is simpler and cruder. However,

the usual type of nuclear mechanism is so complicated that it points strongly to a common ancestry of plants and animals.

The same argument of course works conversely. Thus vertebrates, insects, and cuttlefish all have good eyes, but with three different basic plans, from which it is argued that they were independently evolved from eyeless ancestors. There are many other reasons for believing this. To a geneticist like myself the similarity of plant and animal genetics is a strong argument for the unity of descent of animals and plants.

Let us now consider another set of biological facts. When we say that a man is an individual we mean that he cannot be divided in such a way that both parts go on living. If you divide him at a finger joint the main part survives and the small one dies; though it may be possible to keep part of it alive in tissue culture, but at a low level of life, so to say. If you divide a man in two at the neck, both halves die, with the same reservation.

But now think of a cultivated banana tree. It is constantly putting up new stems, or "suckers" as they are called, from its roots. If left to itself, the original plant will die and leave a circle of descendants round it. But

we may cut the root before this has happened and replant the tiny tree. I say that the banana tree is a dividual (this is quite a respectable English word; it is used with a rather different meaning in Milton's "Paradise Lost").

Few animals are dividuals when adult. But some worms are so, as are the polyps which make coral. However human beings and many other animals are dividuals at a very early age. A fertilized egg cell may divide into two halves, each giving rise to a pair of twins. Such twins are not only of the same sex, but very like one another in build and character, for they have the same genome or *svadharma*. Most plants are dividuals. Even rice which is normally grown from seed can be divided up and the pieces transplanted. Of course cultivated bananas yield no seed; so they can only be reproduced by division, or, as it is often called, vegetative reproduction. As none of the genome is lost in this process, plants so reproduced have the same *svadharma*, the same capacities and needs, as their parent.

But men have treated some dividual plants in a very strange way. Mango trees are constantly growing from seed, and most of them produce very stringy fruits not worth

eating. However, occasionally one bears good fruit. Such a tree can be multiplied by grafting. A twig from it is grafted onto the root from another seedling, and the two heal together to form a new organism which has a physiological unity, even though its parts were grown a hundred miles apart. Insects and even frogs of different species can be grafted together as pupae or embryos. But if a bit of skin is grafted from one human being to another, for example to help in the healing of a serious burn, it lives for some weeks and then dies. The only human tissue which can survive when grafted from one man to another is the cornea, the transparent window in front of the eye. This can be removed, even a few hours after death, and used to replace one which has become opaque through disease or injury. Some, but unfortunately not very many, cases of blindness can be cured in this way. The transplanted part is not dead like a piece of glass, but consists of living cells which are nourished by their new host.

We see, then, that some living organisms can be divided into two, and others can be joined together to make a new one. Presumably the great philosophers were vaguely aware of such facts, though it seems that

tree grafting was introduced into India by Europeans. But I don't think they saw their interest. Had they done so the banana tree would have been a familiar example like the rope and snake or the smoke on the mountain. I should particularly like to have heard Nagarjuna's comments on the propagation of banana trees.

However I want to point out that these facts are very important for Indian economics. It may be possible to divide a coconut palm (*nārikel*) tree, perhaps by growing another from its roots. If so it will be possible to pick out the most fruitful trees in such states as Kerala and West Bengal, and to propagate others as like them as the various members of a named variety of mango or banana are like one another. There are theoretical reasons why this may be very difficult in the case of palm trees.

But with mangoes I believe real progress can and should be made in ten years. Thirty years ago we propagated apples in England much as mangoes are propagated in India to-day. Provided the upper part of the partnership was known to produce good fruit, nobody worried about the root stock, as the lower part is called. Then the workers at East Malling in Kent began to select root

stocks and to propagate them vegetatively. Now we can buy root stocks immune to various diseases. We can also choose one which is known to agree with the scion, or fruiting part, of the compound tree. For sometimes the two are incompatible. But above all, one can choose a stock on which a tall tree will grow, or a dwarfing stock, which will give a nice little tree eight or ten feet high, and bearing fruit after two or three years, suited to a suburban garden. My neighbours at Baranagar mostly have tiny gardens, with no room for a mango tree of the usual size. It may be just as easy to make dwarf trees for them as it has been to make dwarf apple trees in England. I mention these facts because some of you may think that I have been talking about matters of no practical importance. If you enunciate a scientific principle without seeing any practical value in it, that probably means that you don't really understand the principle.

I want now to go back for a moment to genetics. Within a species, such as cattle or rice, every animal or plant is different. (I did not say "every individual" because a rice plant is not an individual, and even a cow, as we saw, is a co-operative commonwealth

as regards the digestion of grass, though an individual as regards the production of milk.) Some of the differences within a species are genetically determined, and often but not always inherited. And there are breeds of cattle and rice whose members are fairly similar. One might ask, is not one breed better than the others, and should it not replace them? Now this is a fair question to ask about some manufactured goods. For example, the best safety razor blade is the one which gives you most shaves for a rupee. And no doubt the best rice is that which gives you most maunds per acre, if you are not interested in its scent and protein content. But which sort will give most maunds depends on when and where you sow your rice. And of all crop plants which I know, rice is the most diverse.

For the whole of India only about forty or fifty varieties of wheat are officially recommended. In any of the climates of India, and on any of the soils, one or other of these will probably give the highest yield. But after testing over 4,000 varieties of rice, the Central Rice Institute recommended nearly 500. Some varieties are suited to upland soils which dry quickly after the rains. Others will grow in water even

twenty feet deep. There are plants suited for different times of year. But those which flower after the rains and are reaped in November or December flower when the night reaches a certain length. At the Central Rice Institute at Cuttack someone erected an electric lamp post by the side of a plot of *āman* paddy. I saw that the plants near it had not flowered except where a metal support had thrown a shadow. In plants which can be grown in pots in artificial light turned on and off without reference to the sun it has been shown that it is the length of night, not of day, which counts. I do not know if this experiment has been done on rice. It is a rather striking demonstration of the unity of life that the development of the reproductive organs and the desire to migrate in some mammals and birds also depends on day length. An extra two or three hours of light will induce some European mammals such as the ferret, which resembles the mongoose, to breed in January instead of March. And birds which are given some extra hours of strong light in the evening do not migrate southwards in autumn if given the chance.

On the same day in late October the night will be longer in Assam than in Andhra,

longer in Andhra than in Kerala. So we need different varieties of rice if they are to flower on the same day in these three states. In spite of this diversity there is a sense in which all the rice plants in India have a unity. By careful crossing one can transfer a character such as resistance to blast disease or sensitivity to night length from one variety to another because it depends on one gene or a small number. It is much harder to transfer desirable characters from Japanese to Indian rice, as the hybrids are partly sterile. And of course one cannot combine the desirable characters in two banana trees. By becoming sterile, bananas have lost this kind of unity.

As a geneticist I am intensely interested in diversity, especially when it is inherited. That is why I found the thousands of rice varieties which I was shown at the Central Rice Institute at Cuttack last October the most exciting spectacle that I have seen in India this year. But diversity is only valuable provided each plant and animal can fulfil its *svadharma*. Otherwise it may be a nuisance. My wife has just started research on tussore silk moths. She bought a batch of 640 cocoons in a market in Bihar. Not only were they unequal in size and silk

yield, but the silks were of several different colours, and so were the moths which came out of the cocoons. Even if it is unexpectedly difficult to improve the yield, it should be quite easy to produce silk of a uniform colour, and this should make at least slightly better cloth than an unpredictable mixture.

However, I am not here to lecture on the possible applications of genetics in India. I do not know enough to do so. I shall go back to the kind of unity which prevails in a highly developed and individual organism such as a man, a bee, or a palm tree. Even before the discovery of cells, it was clear that these organisms consisted of different parts which grew up to form a pattern, and which collaborated together. However, very different views were taken as to the nature of this collaboration, and of the kind of unity achieved. At one end of the scale some thought that every detail was regulated by the soul or *jīvātman* associated with the living matter. At the other end it was thought that a full explanation could be given in terms of the interactions of atoms. There are serious objections to the first view. I certainly do not regulate the details of my digestion consciously. Perhaps, it has been thought, an unconscious part of my soul or

mind does so. Perhaps I contain several souls with different functions. The case of the mango is very awkward for such a theory. Here it would seem that a life or soul had been cut in two, and then two lives or souls fused. If you think you are a living being and the mango only a machine, remember the men who are seeing with parts of other men's eyes. But the interpretation in terms of atomic interactions is at least equally difficult, particularly since physicists now realise that even such a simple atomic property as mass is what is called a co-operative phenomenon, depending on an atom's neighbours as well as on itself.

When we compare a live plant or animal with a machine we find some close analogies. In particular the amount of work or heat which a man or dog can produce from sugar, fat, or many other foods is exactly the same as can be got from burning it. And the successive steps in its utilisation can be imitated very exactly in non-living systems. The attempt to explain the details of bodily processes in terms of physics and chemistry is being very actively pursued, and with complete success. The most striking feature of a living being is however its capacity for self-regulation. The most obvious

example is healing. Torn skin mends itself. Torn clothes do not. And this self-regulation turns out to be the main end to which all bodily activities are directed. There are, of course, machines which regulate some of their activities, for example thermostats. But it is difficult to imagine one which regulated them all. Perhaps such a machine would be alive. I do not know.

I want to consider one activity which is common to many animals, namely breathing. I do not mean the uptake of oxygen, but the rhythmical intake and output of air or water. This is certainly necessary for life in higher animals, and primitive human thinkers all over the world identified breath with life and even with mental functions. Such words as *prāṇa*, *ātman*, spirit, all meant breath originally. When oxygen was discovered, and was found to unite with other substances in flames, it was thought that the function of breathing was to supply oxygen to the vital flame. This is true, but it is not the whole truth. Over fifty years ago my father made the surprising discovery that the breathing is so regulated as to keep the amount of carbon dioxide in the blood supplied by the heart to the other organs remarkably steady. If you walk at four

miles per hour you will increase your production of carbon dioxide per minute to about five times what it was when lying down. But the amount in the blood only rises by about five per cent, because your increased breathing very nearly, but not completely, compensates for the rise.

Again, if you overbreathe voluntarily for some minutes, you will lower the carbon dioxide in your blood, and may neither breathe nor want to for a minute or more. The breathing is not normally regulated by want of oxygen, as you can easily prove by breathing pure oxygen, which does not slow your breathing down. Only when the oxygen in the air breathed falls quite low is there any serious increase in the breathing. A yogi performing *prāṇāyāma* does not suffer from oxygen want, but produces rhythmical changes in the level of carbon dioxide in his organs, which seem to have remarkable effects. Carbon dioxide is a necessity of life. As we normally make more than we need we are constantly getting rid of it, but we cannot live without it.

In the same way the kidneys do not merely serve to get rid of waste products. They can hold back salt most tenaciously if it has been lost through sweating. Hunger

and thirst are feelings generated by abnormal composition of the blood. If you inject some strong salt solution into a man he will feel thirsty long before his mouth has got dry. Breathing is important because the amounts of carbon dioxide and oxygen in our blood change very quickly as the result of chemical events in the body cells. So we cannot survive for five minutes without breathing. The amounts of other substances change much more slowly, so a man can survive for several days without kidneys or without drinking.

Most organic regulation is done quite unconsciously. We do not normally notice our breathing, or the repairs which are constantly going on all over our bodies. If an organ increases its use of oxygen, for example when a muscle contracts or a gland secretes, a very simple automatic mechanism increases its blood supply, and the pressure in the arteries would fall if we did not possess pressure gauges which signal to the heart for an increase of blood flow. The Central Government, in the brain, no more interferes, than the Government at Delhi interferes with the traffic signals in Calcutta.

We might say that the constituents of our body enjoy a good deal of freedom. Even

those which are most obviously under control, the voluntary muscles, are very far from slaves. At first sight the nerve connecting a muscle to the central nervous system seems merely to transmit orders to the muscle. But in fact only a minority of the fibres in the nerves leading to many muscles are doing this. Others are transmitting reports back from the muscle to the central nervous system, and quite a number are regulating the organs in the muscle which send these reports back. Without such a system the muscles could never act with the astonishing precision needed in skilled human work or in the flight of birds.

We see then that a living being consists of a very large number of living constituents, the cells, which are organised into further systems which act as wholes, such as muscles or glands. These have a good deal of autonomy, and even when they are closely controlled, they can and do answer back. The analogy with a state is obvious, though it is dangerous to press it too far. But if we make the comparison we must realise that the kind of state which is most like a living body is one in which there is a great deal of freedom, and criticism of the central authority. A pain may be compared to such

a criticism. It can force the central authority to drop other activities and try to deal with the cause of the pain. I mention one curious analogy. The Prime Minister wishes the Central Government to take over various activities, such as steel making, which have so far been left to private enterprise. He also practises yoga. That is to say he has learned to control some of the activities in his own body which most people leave to control themselves. Now yoga leads to an extension of consciousness as well as of will. It may lead to the experience of *kundalini*, which is said to be a higher level of self-consciousness. Socialistic planning is impossible without very detailed economic knowledge. The Indian Statistical Institute, where I work, is an organ providing knowledge of a kind which does not exist in many other states.

One of the most striking discoveries of physiology is the way in which antagonistic processes achieve a regulation which apparently cannot be achieved in any other way. What happens, for example, when you straighten your arm which was previously bent at the elbow? The muscles in the upper arm above the elbow, such as the triceps, become shorter and thicker, as you

can easily feel. At the same time the stronger muscles which bend the elbow, such as the biceps, relax. But they do not relax completely. If they did, you might straighten your arm so violently as to dislocate your elbow. In fact normally both sets of muscles are pulling to some extent. And the same is true all over your body. This keeps you in a steady posture, but uses up a good deal of energy. If the muscles relaxed completely you would need appreciably less food. This apparently wasteful antagonism, or struggle of opposites, is entirely characteristic of the bodies of higher animals. It also occurs on the biochemical level. For example, the thyroid gland in the neck produces several chemical substances containing iodine which are needed by most other tissues. If there is a shortage of these hormones the resting heat production goes down, and one becomes fat and sluggish. If there is too much, the heat production goes up, and one becomes thin and overirritable. If the thyroid has been removed one can keep a man in good health by giving him the right amount daily. On the other hand one can give half of this amount to a normal man without any appreciable effect. The amount in the blood is carefully

regulated. The activity of the thyroid gland is controlled in turn by the thyrotrophic hormone produced in the pituitary gland, between the brain and the roof of the mouth. If the amount of thyroid hormone falls, a lot of thyrotrophic hormone is poured into the blood, and the thyroid is stimulated to make more of its own hormone. If the amount rises the pituitary ceases to make thyrotrophic hormone. If a physician thinks too mechanistically he may hope to restore health by injecting one or other of two hormones interacting in this way, but it may have no effect at all or the opposite of what is intended. For example, the testis, the male sex gland, pours hormones into the blood which make a human beard or a cock's comb grow, and have many other effects. It might be thought that deficient virility could be restored by injecting plenty of this hormone. On the contrary, you can castrate a male animal by doing so, for one of its effects is to stop the production by the pituitary gland of a hormone which is needed for the function of the testes.

I could multiply examples indefinitely. I want you to believe that at every level stability is achieved by conflict of this kind. Such a system is far more elastic against

external influences than a rigid system such as most man-made machines. A good deal of what we take to be evil in human societies and in the universe is one side of such a conflict. We human beings are seldom wise enough to see that the conflict is part of a large-scale pattern. Lenin, in particular, stressed the necessity of conflict for progress.

I am sure that many of you who have listened to these lectures have been disappointed. You hoped perhaps that I would enunciate some great principle. At best I have only convinced you that life is more complicated than you imagined. If I had stressed the unity of life I could have given a so-called holistic account. Such an account may stop at the individual and present men and animals as isolated units, or it may go further and regard them as mere components in a state or pawns in a divine game of chess. Or I could have stressed details and tried to explain life in terms of the properties of atoms. Either treatment can achieve an intellectual coherence which I have missed. And it is desirable that these views should be developed, for both are fruitful. But I think that a more dialectical view, to use the Marxist phraseology, is nearer to the truth.

Some of you may get an inkling of my point of view by contemplating one of the temples which are among the glories of India. At each moment one's mind is torn between the appreciation of the building as a whole and that of its details. Our European cathedrals of the middle ages produce the same conflict. Some people find the conflict exhausting or intolerable, and prefer buildings with less ornament, or pictures and sculptures in a gallery with no overriding aesthetic plan.

In conclusion, I wish to make it clear that I am not preaching a new philosophy or a new religion. No doubt I have inadvertently told you some untruths. But most of what I have told you is strictly true. And I believe that some of it is so important that it will have to be incorporated into any philosophy or religion which is to command the assent of intelligent men and women. Of course the facts can be expressed in different words. Some of you may think I have not been materialistic enough, others that I have been too materialistic. Anyone who has been influenced by the Samkhya *darśana* will hesitate to make such a criticism. For him or her, a mountain or a flame, and my perception of it and

emotions about it, are equally *prakṛti*, though they are different kinds of *prakṛti*. For the adherents of other *darśanas* they are equally illusory.

I also think that the point of view which I have tried to put forward may help to suggest how some of the practical problems which confront India may be solved. Let me give you one example. The various plants and animals in a natural community such as a jungle form a unity which possesses a certain stability. If for example men kill off carnivorous animals such as wolves and tigers, the numbers of vegetarian animals such as deer may increase until they die of famine and of diseases due to overcrowding. This process has been observed on several occasions in North America. Agriculture upsets this balance, giving a plant community, or a plant and animal community, such as a paddy field or a cow pasture, which is much more easily disturbed by natural causes such as droughts and epidemics. And although it gives a higher yield to men than the natural community, it may not exploit the soil so well. One of the subjects on which I want to get research started is that of mixed crops. There is evidence, for example, that a field sown with a mixture of

about equal parts of wheat and gram will grow more than half as much wheat as if it were planted with wheat only, and also more than half as much gram. Unfortunately this evidence is not as strong as could be desired. We may say that the wheat and gram plants are co-operating, or that they are extracting rather different substances from the soil. Clearly such a field is a little more like a natural plant community than is a field sown with wheat or gram alone. It may be a little more useful to men. Certainly it is more trouble to reap, and is quite unsuitable for mechanical reaping. But as India has little or no mechanization of agriculture and a large rural labour force, it is worth considering. I am hoping that the Indian Statistical Institute may take up once more the investigation of the yield of mixed crops which Professor Mahalanobis started fifteen years ago, but was then prevented from completing.

Rice is rarely if ever grown along with anything else. But Gustaffson's work on barley in Sweden suggests that if a mixture of two different varieties of rice is grown in the same field, the yield will sometimes be higher than that of either alone. This is, of course, a matter for statistical investigation.

I give these two examples out of many in the hope of persuading you that the consideration of the unity and diversity of life is not only an activity of a certain philosophical and cultural value. It is immediately applicable to concrete biological problems, problems which are quite literally matters of life and death to millions of Indians.

I have done my best to discuss life rather than mind or spirit. I have not said for example either that each cell in my body is or is not controlled by a *jīva*, or that my body as a whole is or is not so controlled. Nor have I preached any ethical doctrine. But anyone who has the concrete and detailed notion of the unity of life, at which I have arrived after studying biology for sixty years, will at least have some respect for all life, including plant life. One of the many sights which depresses me in India is that of the millions of mutilated *khajur* palms, many of them slowly dying. I do not think that they feel pain. But pain is certainly not the only evil, and perhaps not the most serious evil.

On the walls of the large room in the zoological laboratory at Münster where Professor Rensch keeps living animals are

written the words "*tat twam asi*". If I have helped any of you to understand some of the implications of this great saying, my lectures have not been in vain.

APPENDIX

Professor Haldane's answers to some questions put to him after the lectures :

Q. Is it possible to get various breeds of cows and buffaloes by means of cross-pollination, as it happens rather quite simply amongst the plants? And if so, do you think it helps the process of evolution as such or only serves the fancies of the experimenter?

A : It is not quite correct to describe the mating of animals as cross-pollination. You have also underestimated the difficulty of making of a new breed of plants by cross-pollination. To take a practical example, Japanese rice breeds in Japan give a higher yield than Indian rice breeds in India. But they do not do so in India, not being adapted to our climate. Dr. Ghose and his colleagues at Cuttack are crossing them in the hope of getting plants which combine the high yield of the Japanese plants with the adaptation to heat of the Indian plants. But the hybrids mostly show partial sterility, even after several generations. However, in similar cases one plant in ten thousand combining the desired characters has been picked out and used to found a new breed.

Unfortunately it is not practicable to breed ten thousand cows in the hope of finding one which will give as high a milk yield as good European breeds under Indian conditions. It would be possible to do this with silkworms, and I hope that it will be attempted.

You ask me whether I think it helps the process of evolution as such or only serves the fancies of the experimenter. I don't think this question has any definite meaning. Evolution is just a word for the fact that existing animals and plants differ from their ancestors in the remote past. The changes which have

produced our present domestic animals, including fancy breeds such as fantail and pouter pigeons, are part of evolution. Fancies, as you call them, have been very important in evolution. Flowers evolved, as I believe, because they attracted insects and occasionally birds. What you are perhaps asking, is whether domestic animals have any future. It is likely, for example, that silkworms will be completely superseded by factories making synthetic fibres such as nylon. It is possible that cows will be superseded by factories making substances with the nutritive value of milk either from plants or directly from air and minerals. If so the domestication of cows will have been a side show, so to speak, of evolution, and cows have no important future. As a biologist I hope that men will continue to keep domestic animals for millions of years. But I don't know, so I can't answer your question.

Q. The millions of cells that constitute a human being, plant or animal, have all developed from a single cell by a process of multiplication by division, and are therefore of identical structure and contain the same chromosome composition. Is there anything in recent researches which throws light on the mechanism or the methods by which cells of identical structure develop into cells of such varying capacities as brain cells, muscle cells, bone cells, etc.?

A : The cells in a human being, plant, or animal certainly do not all have the same number of chromosomes. For example, many cells in the human liver have double the usual number. Dr. Sharma and his colleagues at Calcutta University are finding many cases where the nuclear chromosome number in a plant's leaves differs from that in its stem. However, most of the differences between cells in the same body do not seem to be determined by the chromosomes, though some are. Whereas most of the differences between members of a species are determined by the chromosomes, though some are not. A good deal of experimental work has been done on the transplantation of nuclei from one cell to another. The results

are not yet quite clear, but seem to show that the cytoplasm, rather than the chromosomes, is usually responsible for differentiation. In his *Principles of Embryology* (London 1956) Waddington has recently reviewed the evidence on this question. I don't think I could give a fair summary of it in less than half an hour.

Q. Yesterday, you referred to the language of the bees as one of the greatest discoveries of the age. Is this language capable of being formulated and studied as visual or auditory symbols, in the sense that by learning it human beings can follow discussions in a honeycomb? Or, is the language of the bees still largely a matter of conjecture?

A : By looking at a "dancing" bee one can say that it is signalling to other bees to fly (say) 550 yards in a direction thirty-five degrees to the right of the sun's direction. If different bees are recommending different nesting sites one can follow the debate. You will find records of such debates by Lindauer in "Die Naturwissenschaften" for 1951, and one of these is reproduced on page 169 of Ribbands' *The Behaviour and Social Life of Honeybees* (London 1953). There is nothing conjectural about the communication of direction and distance, and with a protractor and a stop-watch a man can easily interpret it. However bees certainly communicate on other matters besides the direction and distance of flights to be undertaken, and we do not yet know much about how they do it. It is much easier to learn to understand the bees' signals about where food is to be found than to learn a human language. One of my laboratory assistants in London used to give a very exaggerated imitation of me looking through a glass window into a beehive, waggling my own body in sympathy with the bees, and saying "No, 400 yards, not 500" and so on.

Q. It has been mentioned as a possibility that cosmic rays effect changes in the germ plasm. Have any recent researches indicated any other factor, such as

environmental factors, influencing changes in the germ plasm? Or, is there anything inherent in the germ plasm itself, which under certain stresses, makes for its own transformation? Have any recent researches thrown any light on the factors which make for evolutionary changes?

A : The "germ plasm", an expression which is never used by contemporary biologists, and which I dislike, as it seems to me ambiguous, can be altered by a great many other agencies than cosmic rays. These include X-rays, gamma rays from radio-active substances, and quite a variety of chemical compounds. A great many compounds produce mutations if they can reach the chromosomes. But many substances which can reach the chromosomes in plants, and even insects, seem to be stopped before they reach them in higher animals such as men. I have tried to summarize what I believe to be the facts about evolutionary change in a lecture to the Indian Science Congress at Madras which has been published in the Journal of Industrial and Scientific Research, Delhi. I do not think it likely that the agencies which control the frequency of mutation have any serious influence on the rate or direction of evolution. Mutations are constantly occurring. Natural selection determines whether they will have evolutionary consequences.

Q. Cannot all these "behaviour patterns" of animals and plants be explained by purely reflex action and conditioned reflexes?

A : I do not think that the conception of reflex action is of much value, if any, in explaining the behaviour of plants, for example in flowering when the night reaches a certain length. Reflex action demands a nervous system. And I do not think that reflex action, conditioned or otherwise, is an adequate account of the more complicated kinds of animal behaviour. Let us take such a familiar case as the imitation of human speech by a parrot. The parrot has no inborn urge or "brain mechanism" to

make it say one human word rather than another, as it has an inborn capacity for flight or cracking seeds. And it imitates human words without any conditioning, even if it does so better or more often if rewarded. For more complicated activities an explanation in terms of conditioned reflexes seems to me even more difficult.

Q. You said science will produce life. Will science ever conquer death?

A : I never said that "science will produce life". I said that scientists would try to do so, a very different matter. They may or may not succeed. I object to the phrase "Will science conquer death ?" because it is a double metaphor. Science does not do things. Men do; and conquest is also a metaphor. If you mean, "Will men, using scientific methods, abolish death?" I think it most unlikely. But they may conquer it in the sense of making it no longer feared. Hinduism and Buddhism both teach that it is an evil that men should die with unsatisfied desires. I agree with them, though I have yet to be persuaded that such a death leads to rebirth. I think that premature death is an evil which can very largely be avoided. And I think that the attitude which I regard as scientific enables some people to understand their desires and other affects, and thus to approximate to the state of equanimity described in the fifth book of Spinoza's *Ethics*. It is commonly held in India that one can only achieve non-attachment by renunciation. I think there is another possibility outlined in William Blake's verses.

"He who binds to himself a joy
Does the wingèd life destroy,
But he who kisses the joy as it flies
Lives in eternity's sunrise."

A scientific study of psychology may show that enjoyment without attachment is a possibility. Certainly it demands considerable self-discipline. And most people in India today do not have adequate

opportunities to enjoy life. However I think that just because I have enjoyed life more than most people, I shall be less reluctant to relinquish it. If "science" can give us long, healthy, and happy lives, with sufficient knowledge of psychology, and means of applying that knowledge, to prevent attachment to objects of desire, then it will not be senseless to say that it has conquered death.

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